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RESEARCH DEPARTMENT

REPORT

The improved display of 625-line television pictures: Adaptive interpolation

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ADAPTIVE INTERPOLATION

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Summary

Some of the defects of a conventional 625-line television scanning system can be reduced, or even eliminated by signal processing in the receiver. The processing need not be very complicated, and most scanning system defects can be treated merely by raising the display scanning rate by standards conversion, for example to a sequential structure of 625-lines at 100 pictures a second, or an interlaced structure of 1250 lines at 100 fields a second.
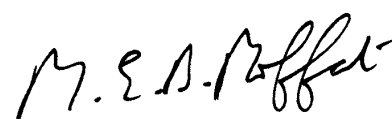
Although such structures do not suffer from the defects of the conventional 625-line system, other effects can arise if unsuitable conversion algorithms are used, Specifically, it is possible to define two algorithms, one best suited to the portrayal of motion, the other to vertical detail, and no compromise is suited to both.

This Report describes an adaptive solution to the problem, involving varying the algorithm according to the output of a motion detector such that the appropriate algorithm was used for each pixel.

The work was not completely successful, in that the motion detector could not be adjusted to give completely acceptable results, although for non-critical test material the results were encouraging.

It is believed that additional, three dimensional, filtering in the motion detector could result in satisfactory performance, but that such filtering would probably be too complex to be used in any receiver during the next five to ten years.

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1. Introduction

In a previous Report[1], describing work on the improved display of 625-line television, it was stated that some of the defects of the 625-line scanning system can be distracting when seen on a modern television receiver, and that trends in receiver design towards higher brightness and larger screen sizes will further aggravate the situation. Large area brightness flicker and interlace effects, such as interline twitter and line crawl, can be quite disturbing. The Report described methods of removing or reducing some of these defects, by signal processing in the receiver based on changing the line and/or field scanning rates, and many structures were investigated. However, it was concluded that the conflicting requirements of the adequate portrayal of both vertical detail and motion could be resolved only by adopting an interpolation algorithm specifically designed for each, necessitating an adaptive interpolator, controlled by a scene motion detector. This Report describes the development and performance of such a system.

2. Performance of the interpolation algorithms

In the previous work, two general purpose algorithms were described, applicable to most of the proposed display structures. They will be described here applied, for simplicity, to only a 625/100/2:1 interlaced structure. This will reveal all the problems associated with this form of standards conversion. As mentioned earlier, the signal processing is intended for use in a receiver, and thus should be as simple as possible. Large,

multi-term, interpolators are not attractive because of excessive cost.

2.1. Detail algorithm

The detail algorithm is shown in Fig. 1, where 0 denotes a line of the 625/50 source structure and X denotes a line of the 625/100 display structure. The figure is drawn in the vertical/temporal plane with time progressing to the right. Arrows indicate the contributions of input lines to output lines, numbers indicating the weighting factors. As can be seen in Fig. 1 contributions are taken only from the spatially accurate line in the temporally nearest field.

All the weighting factors are unity, so no interpolation takes place and all vertical detail is preserved, thus there can be no algorithm better suited to the preservation of vertical detail. The identity of the odd and even fields is preserved, and the interline-twitter frequency is raised to 50 Hz, where it is imperceptible. Motion portrayal by this algorithm is very poor. As can be seen from Fig. 1, the sequence of output fields is not derived monotonically from the input signal, resulting in a cyclic reversal in the temporal sequence. This reversal gives rise to a strong 25 Hz component in the output signal, resulting in a disturbing motion judder which is not unlike the judder seen on film.

Although this algorithm portrays vertical detail perfectly on a 625/100/2:1 interlaced structure, a more complex algorithm is required for use on any 1250-line structure. It is beyond
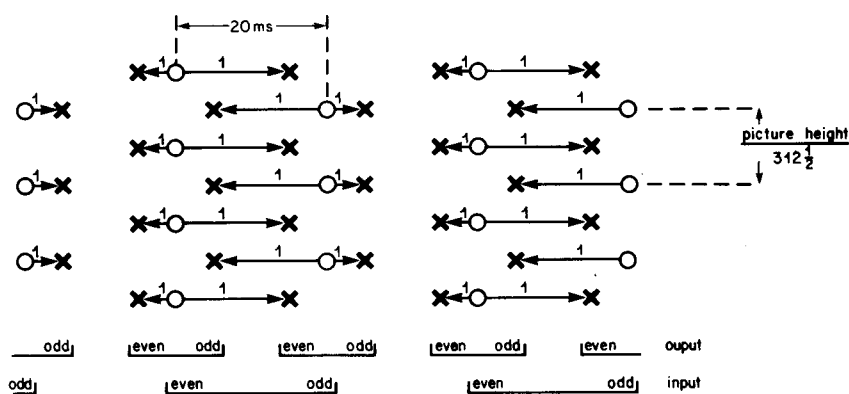

Fig. 1 — Detail interpolation algorithm.

the scope of this Report to discuss such algorithms.

2.2. Motion algorithm

The motion algorithm is shown in Fig. 2. The weighting factors for alternate output pictures (field pairs) are 1 and ½, requiring the use of a one line-delay interpolator. Each output field is derived entirely from the temporally nearest field, interpolation being used to generate lines in new vertical positions as required.
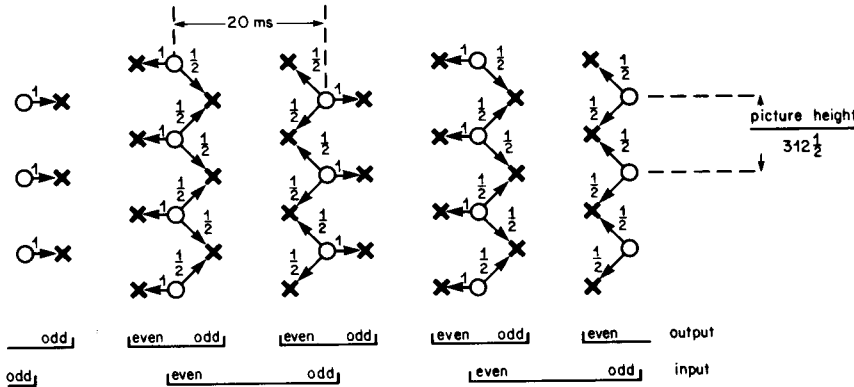
is added to the sum of the algorithms. Thus:

$$O/P = \tfrac{1}{2}(\text{motion} + \text{detail}) + \tfrac{1}{2}(\text{motion} - \text{detail}) \times M$$

$$= \tfrac{1}{2}\left\{ \text{motion}\,(1 + M) + \text{detail}\,(1 - M) \right\}$$

As M is varied between −1 and +1, so the interpolator is 'faded' between the two algorithms.

Fig. 2 — Motion interpolation algorithm.

Motion portrayal is smooth since the flow of information is monotonic. However, vertical detail at high vertical frequencies is attenuated in the interpolated pictures which have a zero response at 312½ cycles per picture height. The combination of alternating interpolated and non-interpolated pictures gives a subjective softening of the picture, together with a 25 Hz flicker. Both effects are due to the zero response at 312½ cycles per picture height in the interpolated fields, the eye averages the two types to give a 6 dB dip in the vertical frequency response, and detail at or near this frequency flickers at 25 Hz. Thus, the motion algorithm gives poor performance on static pictures.

3. The adaptive interpolator

An adaptive interpolator was built, comprising a variable interpolator and a motion detector.

3.1. Interpolator

A block diagram of the interpolator is shown in Fig. 3. The two switches are driven by odd/even field identification waveforms derived from the input and output scanning structures, and simultaneously produce video signals according to the detail and motion algorithms. The difference between the algorithms is multiplied by a factor, M, derived by the motion detector, and the result

3.2. Motion detector, basic form

The motion detector[2] measures the significance of motion and vertical detail in the scene and produces the signal M which controls the interpolator. It does this using temporal and spatial difference signals derived as shown in Fig. 4. The output line to be generated can lie anywhere within the central diamond; if a line lies outside the diamond, the interpolator will output the nearest of the input lines, without interpolation.

The difference signals are generated by unsigned subtraction, thus the temporal difference signal, $D_T = |A - B|$ and the spatial difference, $D_S = |C - D|$. In practice, it is also necessary to generate the central signal, by averaging, thus

$$\Sigma = \frac{A + B}{2},$$ the reason for this will become clear

later. A block diagram of the motion detector is shown in Fig. 5. The two differences, D_S and D_T, are compared and the larger is taken as the dividend into a logarithmic division, with the mean of D_S and D_T as the divisor. The division quotient m is thus:

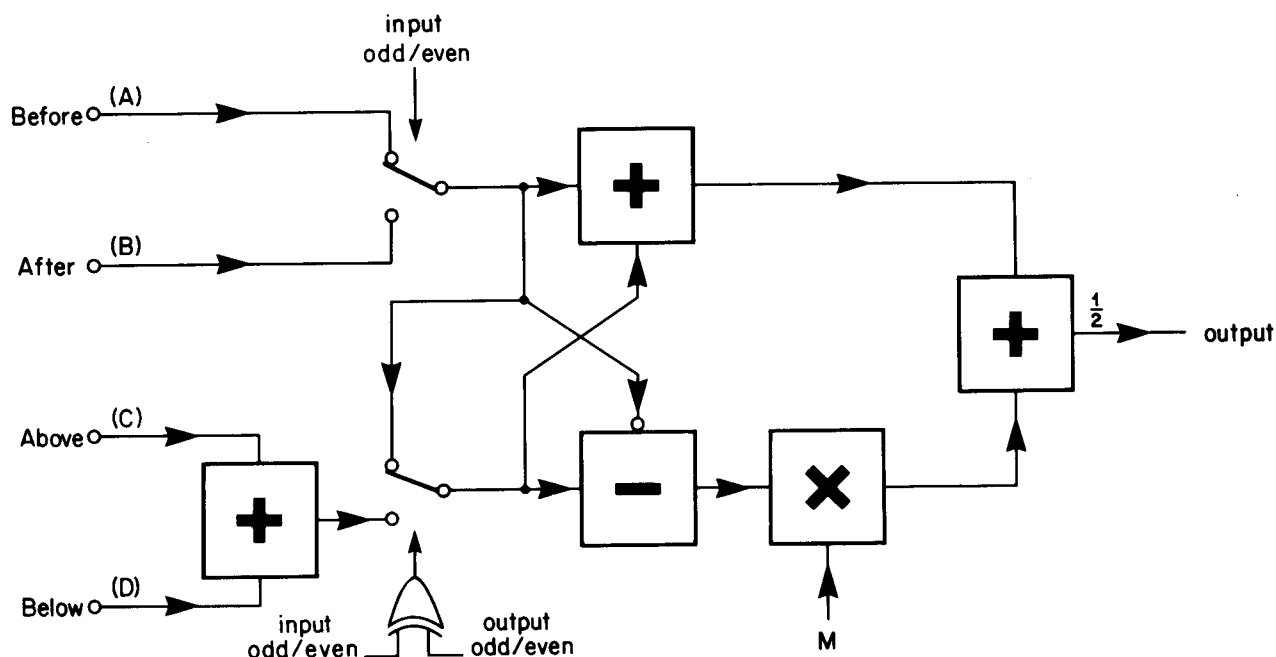$$m = \frac{2 \times D_S}{D_S + D_T} \text{ if } D_S > D_T$$
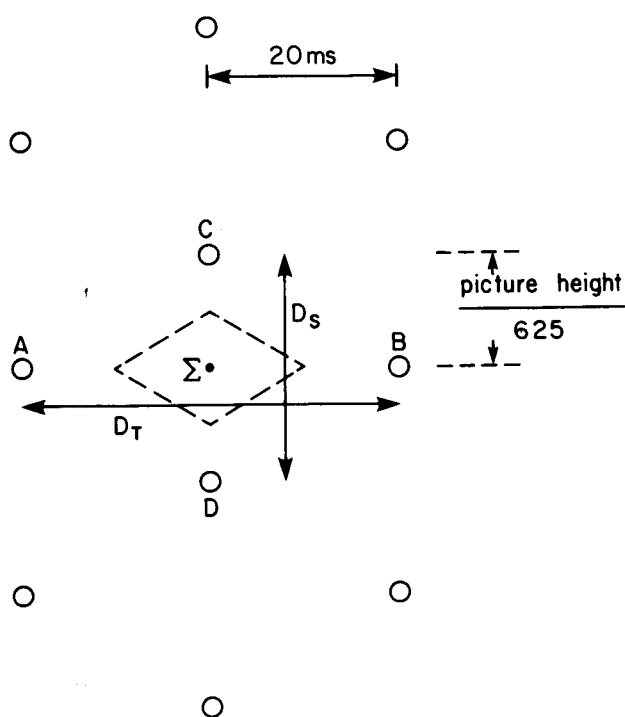
Fig. 3 — Variable interpolation.

Fig. 4 — Spatial and temporal difference signals in the vertical-temporal plane.

$$= \frac{2 \times D_T}{D_S + D_T} \text{ if } D_T > D_S$$

and by subtracting 1,

$$|M| = m - 1 = \frac{D_S - D_T}{D_S + D_T} \text{ if } D_S > D_T$$

$$= \frac{D_T - D_S}{D_S + D_T} \text{ if } D_T > D_S$$

the sign of M is taken from the magnitude comparison. The value of M varies from −1 to +1, irrespective of the magnitudes of D_T and D_S, and is thus representative of the relative significance of motion and detail.

The performance of this basic motion detector is poor, since equal weighting is applied to the difference signals. In practice, the eye can discern vertical detail with smaller amplitude than the motion detector can reliably detect, and the detector is blind to all detail at 312½ cycles per picture height. Also, when both D_S and D_T are small, very small changes in either quantity cause very large changes in M which are plainly visible on the output picture from the controlled interpolator as noise or 'speckle', therefore an improved detector was built.

3.3. Improved motion detector

In the improved detector, the spatial difference term, D_S is replaced by the mean of two differences, D_S' and D_S''. There are generated by using the terms:

$$D_S' = |C - \Sigma| = C - \frac{A + B}{2} \quad \text{and}$$

$$D_S'' = |D - \Sigma| = D - \frac{A + B}{2}$$

By using the mean of D_S' and D_S'', sensitivity to vertical detail is maintained up to 312½ cycles per picture height. In the following discussions D_S will represent the mean of these two differences.

In order to control the performance of the detector, the following form was adopted:

$$M = a \left\{ \frac{b \times D_T - (D_S + c)}{b \times D_T + (D_S + c)} \right\}$$

where 'a' is the overall gain of the detector.

'b' controls the relative sensitivity of the detector to motion and detail.

'c' is an offset, a quantity which b x D_T must exceed before M departs from −1.

'a' must be greater than 1 to ensure that M actually reaches its limits of ±1. 'b' effectively controls the slew rate of M; too large a value results in M being 'active', too small a value might result in slow motion not being detected. 'c' must

be greater than zero to protect low level detail in the presence of motion. The ratio b/c should have a value of between 10 and 20. Typical values of 'a', 'b' and 'c' are 1.5, 2 and 0.15. These were determined empirically as a good compromise.

The performance of this motion detector is considerably better than that of the original; very low amplitude high-frequency detail is adequately protected, and motion portrayal is largely acceptable. However, problems can arise in the transition region in which the interpolator is driven from one algorithm to the other. In pictures where detail is small in amplitude and motion is slow, there can be uncertainity over the exact location of the change in algorithm, and noise can cause this position to vary on successive fields. Thus an individual picture element may be presented by either algorithm in rapid succession. The differences in spatial frequency response, mentioned in Section 2, give rise to a 'speckle' effect in this transition zone. Clearly it is desirable for the motion detector to control the interpolator such that transitions are made only in insentive areas of the picture, surrounding the critical parts, this requires a filter or spreader to be used, ideally in three dimensions. A one-dimensional spreader was built to assess the value of the technique; in a five picture-element window the most positive value of M occuring was applied to the whole window, thus horizontally spreading the effect of
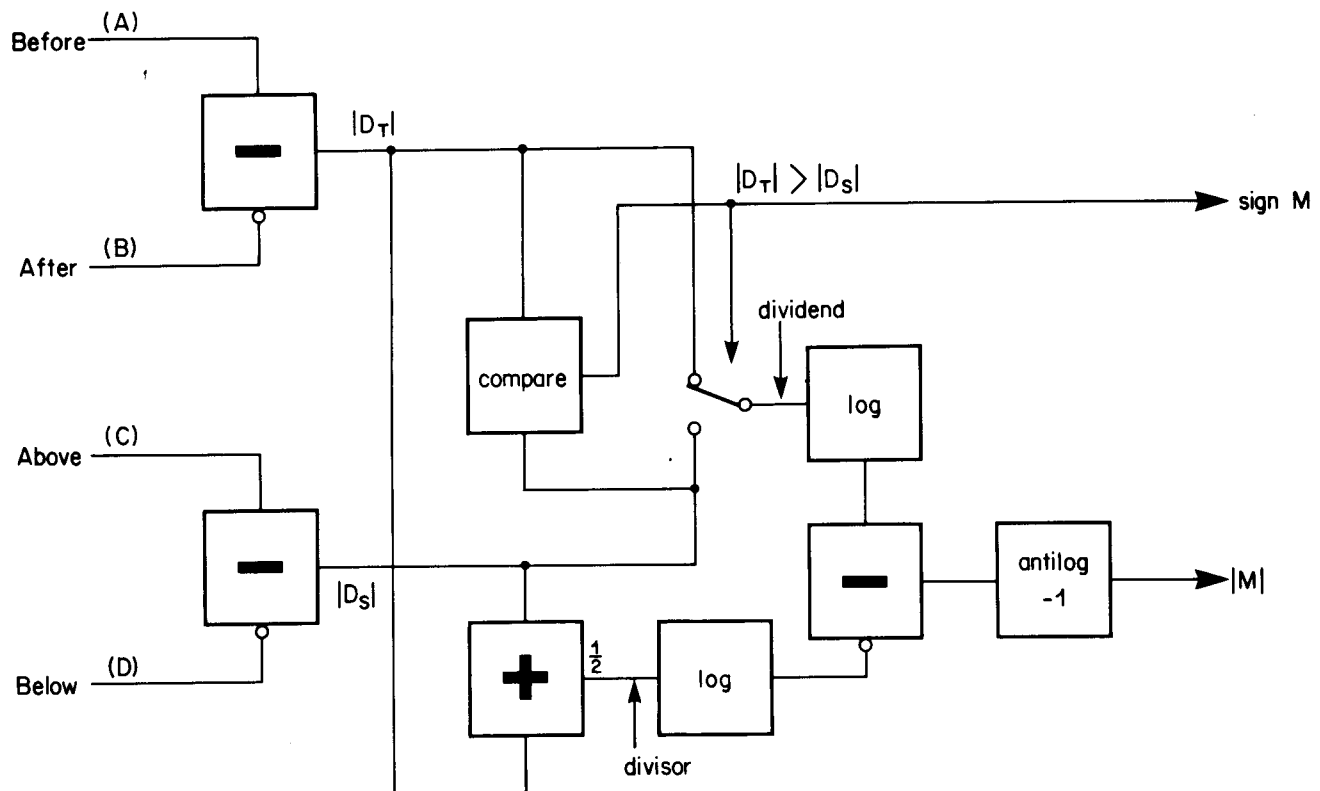

Fig. 5 — Motion Detector.

the motion detector. This technique greatly reduced the speckle effect at low, horizontal, motion speeds, indicating that a three-dimensional spreader would be of benefit. Spreading is, however, of only limited use, since at high speeds, speckle will reappear, when the translation time of a moving edge is less than the transit time of the spreader aperture. If the aperture can be made sufficiently large, for example, 9 elements x 9 lines x 3 fields, the effect might not be visible on normal pictures before motion speeds are so high that resolution in the moving area is lost through camera integration. Unfortunately, such a filter would use a large amount of storage and would significantly raise the cost of the motion detector.

3.4. Alternative motion detectors

As an alternative to the motion detector described above, some experiments were carried out using, as a motion indicator, the output from the measurement sidechain of a video noise reducer[3]. This signal is derived from a picture difference signal, D_T, using a spatial filter with an aperture of 5 lines x 17 elements. The signal was generated at the 625/50 standard, whereas it was required to drive the interpolator at the output standard of 625/100. To overcome this difficulty, it was sliced to form a one bit signal and passed through the standards-converter as the least significant bit of the eight available for the video signal, the video occupying the remaining seven bits.

The results obtained by using this motion 'flag' were encouraging, in that the algorithm switching always occurred sufficiently far from the actual moving image to avoid serious 'speckle'.

The use of a continuous (eight bit) signal would probably have given better results.

4. Conclusions

It was shown in an earlier Report[1], that some defects of the conventional display of 625/50 signals could be eliminated by raising the line and/or field rates using a standards-converter. It was also shown that separate interpolation algorithms were required for the satisfactory portrayal of motion and vertical detail. This Report has described an adaptive interpolator, controlled by a simple motion detector, which is capable of fading between two such algorithms almost imperceptibly. The work was not completely successful, in that the motion detector could not be adjusted to give completely acceptable results, although for non-critical test material the results were encouraging. The action of the motion detector could be improved by the use of a two or three dimensional filter, but the complexity might preclude its use in a domestic receiver during the next five to ten years.

5. References

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3. DREWERY, J.O., STOREY, R., TANTON, N.E. Video Noise Reduction. BBC Research Department Report No. 1984/7.